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Original communication

Discriminant functions for sex estimation of modern Japanese skulls

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ABSTRACT

The purpose of this study is to generate a set of discriminant functions in order to estimate the sex of modern Japanese skulls. To conduct the analysis, the anthropological measurement data of 113 individuals (73 males and 40 females) were collected from recent forensic anthropological test records at the National Research Institute of Police Science, Japan. Birth years of the individuals ranged from 1926 to 1979, and age at death was over 19 years for all individuals. A total of 10 anthropological measurements were used in the discriminant function analysis: maximum cranial length, cranial base length, maximum cranial breadth, maximum frontal breadth, basion-bregmatic height, upper facial breadth, bizygomatic breadth, bicondylar breadth, bigonial breadth, and ramal height. As a result, nine discriminant functions were established. The classification accuracy ranged from 79.0 to 89.9% when the measurements of the 113 individuals were substituted into the established functions, from 77.8 to 88.1% when a leave-one-out cross-validation procedure was applied to the data, and from 86.7 to 93.0% when the measurements of 50 new individuals (25 males and 25 females), unrelated to the establishment of the discriminant functions, were used.

1. Introduction

Sex estimation is one of the important factors contributing to the personal identification of skeletal remains. There have been many studies on estimating sex from bone samples, and forensic scientists and physical anthropologists have traditionally employed morphological and anthropometric methods.[1,2]

In the morphological method, sex is estimated by the visual judgment of sex-dependent morphological traits of bone samples.[1,2] The skull and pelvis are usually regarded as the most reliable indicators of sex estimation in cases where a complete skeleton is available for identification. An advantage of this method is the ability to obtain results quickly with high classification accuracy: 92% if the skull is available, 95% if the pelvis is available, 98% if both are available, and 100% if the entire skeleton is present.[1] However, judging the sex can be problematic in some cases, because the classification criteria for this method are somewhat subjective and some of the bone samples may show features between those of males and females. Although well-trained examiners may achieve high classification accuracy with this method, they require special training and experiences that cannot be given to every forensic biologist. Therefore, an anthropometric method should be used in combination with the morphological method. Anthropometric measurements can be used in two ways for sex estimation. The first is to compare the measurement value obtained with the average values of each sex and the second is to classify the value by using discriminant functions.[3–14] One of the main advantages of anthropometric methods is that more objective results can be obtained compared with the morphological method. Therefore, many studies on anthropometric methods are still being reported and their results are currently widely used in actual forensic cases.[9–14]

Although anthropometric methods are helpful for sex estimation, they can have limitations when applied to actual cases. A notable problem is that the reliability of a method shown in its original research report is applicable only to the same, or highly similar, population groups in terms of race, historical period, and region. Many genetic and environmental factors are considered to influence skeletal shape, including the effects of migration and heterosis, nutritional condition, and diet,[1] and changes in these factors may degrade the reliability of the method. Consequently, we need to generate population-specific discriminant functions and sufficiently validate their classification accuracy.[15,16] Moreover, these functions should be regularly updated.

The skull is one of the most important parts of the skeleton in the fields of forensic anthropology and legal medicine.[1,2] Skulls

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provide considerable information that is helpful for personal identification, such as sexual characteristics, age, and morphological similarity with facial photographs in craniofacial superimposition.[17] Some discriminant functions based on skull measurements have been reported that are specific to sex estimation for Japanese individuals.[5–8] However, the majority of these functions have been generated from data obtained from the older Japanese population. Osteometric and somatometric research has demonstrated that the skull shape of the Japanese population has changed rapidly over the last 100 years due to considerable secular changes.[18–20] In previous research, we evaluated Hanihara's 1959 discriminant function analysis[5] by using measurements obtained from recent skulls and confirmed this secular change in skull shape.[21] To overcome the lack of reliable discriminant functions for the sex estimation of modern Japanese skulls, we have attempted to generate a new set of functions by using Japanese anthropometric measurements collected during recently performed forensic casework.

2. Materials and methods

2.1. Collection of anthropological measurement data

Anthropological measurements of skulls were obtained from forensic anthropological test records kept at the National Research Institute of Police Science, Japan. A dataset consisting of 113 modern Japanese individuals (73 males and 40 females) was chosen for analysis. Their age at death was restricted to over 19 years and their birth years ranged from 1926 to 1979. The individuals chosen were all successfully identified, with at least one of the following methods providing a sufficiently positive result: craniofacial video superimposition,[17] X-ray image comparison with the frontal sinus,[22] comparison with dental records, and DNA analysis. The 10 skull measurements shown in Table 1 were used for statistical analysis. Each measurement was performed according to the method introduced by Martin and Saller.[23]

2.2. Discriminant function analysis

To confirm that the measurements of each skull characteristic were normal distributed, Shapiro–Wilk tests were performed. The statistical significance of the differences between the sexes was confirmed by one-way analysis of variance (ANOVA). The equality of the variance and covariance matrices between males and females was confirmed by Box's *M* test. Stepwise and direct discriminant function analyses were then performed to establish the discriminant functions. The stepwise analysis was performed with the parameter "$F = 2.00$ to enter, $F = 1.99$ to remove". We adopted this parameter for the stepwise method as it was considered to be the most effective for distinguishing between two groups in a previous study.[24] Data collection and statistical analysis were performed with SPSS ver. 16 for Windows.[25]

Table 1
Anthropological measurements used for discriminant function analysis.

Skull measurement*		Measurement landmarks**
Martin's no.		
1	Maximum cranial length	Glabella (g) – Opisthokranion (op)
5	Cranial base length	Nasion (n) – Basion (ba)
8	Maximum cranial breadth	Euryon (eu) [left] – (eu) [right]
10	Maximum frontal breadth	Coronale (co) [left] – (co) [right]
17	Basion-Bregmatic height	Basion (ba) – Bregma (b)
43	Upper facial breadth	Frontomalare – temporale (fmt) [left] – (fmt) [right]
45	Bizygomatic breadth	Zygion (zy) [left] – (zy) [right]
65	Bicondylar breadth	Kondylion laterale (kdl) [left] – (kdl) [right]
66	Bigonial breadth	Gonion (go) [left] – (go) [right]
70	Ramal height	Gonion (go) – highest point of the Ramus

*,**: Skull measurements and measurement landmarks were derived from Martin.[23]

2.3. Reliability validation of established discriminant functions

Three evaluations were performed to validate the classification accuracy of the established discriminant functions.

Validation 1: The measurements of the 113 individuals used to generate the discriminant functions were substituted into each function.

Validation 2: A leave-one-out cross-validation using the measurements of the 113 individuals was applied to each function.

In Validation 1, firstly, all the measurements (113 individuals) were used to generate a discriminant function. Secondly, we investigated whether each of these measurements could be correctly classified by applying the generated discriminant function. Finally, we calculated the classification accuracy, which is defined as the ratio of correctly classified measurements to total measurements. If the sex estimated by a generated discriminant function corresponded to the sex of the individuals identified by the method described in Section 2.1, we regarded the sample as correctly classified. In Validation 2, firstly, a discriminant function was generated from the measurements (112 individuals) that remained when one sample was left out. Secondly, we investigated whether the left out sample could be correctly classified by the generated discriminant function. The procedure was repeated so that each of measurements (113 individuals) is left out once and classified. Finally, we calculate the classification accuracy, defined as in Validation 1.

Validation 3: Skull measurement data of 50 new individuals (25 males and 25 females) were collected from the same archive of forensic case records and substituted into each function. These new individuals were different from the original 113 in regard to the goal of identification. They could not be personally identified due to a lack of references, but their sex was determined by multiple anthropological sexing, including observation of the subpubic angle, of the almost complete skeletons. In some of the cases, DNA analysis on the amelogenin locus supported the sex estimation. Firstly, all the original measurements (113 individuals) were used to generate a discriminant function. Then each of the new measurements (50 individuals), which were not used to generate the function, was classified. The classification accuracy was calculated as described above. Although the personal identities of these 50 individuals are unknown, they are expected to have similar morphological characteristics. Therefore, Validation 3 allows for further verification of the reliability of a discriminant function.

3. Results

The Shapiro–Wilk tests verified that all of the measurements studied were normally distributed with $P > 0.05$ (data not shown). Table 2 lists the basic statistics of the skull measurements and the results of the one-way ANOVA. All of the measurements chosen showed statistically significant differences between male and female ($P < 0.01$). Table 3 lists the results of the discriminant function analysis. A total of nine discriminant functions (eight for the cranium and one for the mandible) were established. Functions 1 and 9 were generated by the stepwise method. Four variables {cranial base length (at Step1), maximum cranial length (at Step2), maximum frontal breadth (at Step3), and bizygomatic breadth (at Step4)} were selected in function 1 from the seven cranial measurements, and two variables {bigonial breadth (at Step1) and ramal height (at Step2)} were selected in function 9 from the three mandible measurements.

Table 2
Basic statistics of anthropological measurements and comparison of mean skull measurements.

Skull measurement	Male			Female			*F*-ratio	*P*-value	
	n	Mean (mm)	SD	*n*	Mean (mm)	SD			
Maximum cranial length	73	179.4	6.56	40	169.4	7.04	57.55	0.000	***
Cranial base length	73	103.8	4.74	39	96.3	4.04	69.92	0.000	***
Maximum cranial breadth	69	145.9	5.44	39	140.6	5.27	24.27	0.000	***
Maximum frontal breadth	71	120.9	4.76	40	114.6	4.24	47.94	0.000	***
Basion-Bregmatic height	73	142.2	5.47	39	134.0	3.79	69.87	0.000	***
Upper facial breadth	72	105.7	3.85	40	99.8	3.92	59.41	0.000	***
Bizygomatic breadth	71	136.5	4.75	35	129.0	3.84	66.46	0.000	***
Bicondylar breadth	55	125.0	4.88	23	121.2	3.80	11.11	0.001	**
Bigonial breadth	60	102.6	5.66	24	95.5	5.13	28.38	0.000	***
Ramal height[a]	57	64.3	5.40	25	58.3	5.38	21.61	0.000	***

Significance: **$P < 0.01$, ***$P < 0.001$.
[a] If we could use either the left or right side, we chose the higher of the two. If one side was broken, we used the other side.

To handle cases in which some of the variables in function 1 are immeasurable due to partial fragmentation of the cranium, we generated a further seven functions by the direct method. Four measurements were selected as variables in functions 2, 3, 4, and 5, and three measurements were selected in functions 6, 7, and 8. Those selected were: in function 2, maximum cranial length, cranial base length, maximum frontal breadth, and upper facial breadth; in function 3, maximum cranial length, maximum frontal breadth, basion-bregmatic height, and upper facial breadth; in function 4, maximum cranial length, cranial base length, upper facial breadth, and bizygomatic breadth; in function 5, maximum frontal breadth, basion-bregmatic height, upper facial breadth, and bizygomatic breadth; in function 6, cranial base length, maximum frontal breadth, and upper facial breadth; in function 7, maximum cranial length, cranial base length, and maximum frontal breadth; and in function 8, maximum cranial length, maximum frontal breadth, and basion bregmatic height. The constant shown in Table 3 is taken from each discriminant function. We selected these variables carefully in consideration of the correlation between each of the variables and the influence of multicollinearity.

A discriminant score is obtained by using these functions. The sectioning point is zero. A discriminant score greater than zero indicates male and that less than zero indicates female.

For example, the discriminant function and discriminant score for function 1 is given as:

$$\begin{aligned}\text{Discriminant score} = \; & (0.039 \times \text{Maximum cranial length}) \\ & + (0.086 \times \text{Cranial base length}) \\ & + (0.085 \times \text{Maximum frontal breadth}) \\ & + (0.092 \times \text{Bizygomatic breadth}) \\ & - 38.15\end{aligned}$$

In an actual forensic case, if we have one skull {Maximum cranial length (measurement: 170.0 mm), Cranial base length (measurement: 98.0 mm), Maximum frontal breadth (measurement: 116.0 mm), Bizygomatic breadth (measurement: 135.0 mm)}, the calculated discriminant score is -0.812 $\{=(0.039 \times 170.0) + (0.086 \times 98.0) + (0.085 \times 116.0) + (0.092 \times 135.0) - 38.15\}$. We can then estimate the sex of this sample as “female” because the discriminant score is smaller than zero.

The equality of the covariance matrix was confirmed in all functions ($P > 0.05$) by Box’s *M* test (data not shown). Table 4 lists the results of validations 1–3 for each of the established discriminant functions. The classification accuracy ranged from 79.0 to 89.9% in validation 1, from 77.8 to 88.1% in validation 2, and from 86.7 to 93.0% in validation 3.

4. Discussion

In this study, we generated a new set of sex discriminant functions for the skull by using recent anthropological measurements of Japanese skulls.

Ten of the 25 anthropological measurements presented in our previous report[21] were selected in the preliminary stage as candidates for the discriminant function analysis. These measurements were intentionally selected in consideration of the following two points. Firstly, measurements must be robust against variability in examiner proficiency. Many previous reports[5–7] have mentioned the importance of generating practical discriminant functions that utilize measurable characteristics from clearly identifiable landmarks. Such characteristics decrease the possibility of inter- and intra-examiner measurement error. Accordingly, we eliminated measurements related to obscure landmarks, such as orbital height, orbital breadth, biauriclare breadth, minimum frontal breadth, and biasterionic breadth. Those measurements have also been candidates for elimination in previous reports that have considered the measurement errors in analyses.[26,27] We consider this notion to be valid based on our own experiences in actual cases. Secondly, measurements must be robust against partially broken skulls. In actual forensic cases, we often encounter parts of bones that are

Table 3
Discriminant functions for crania and mandibles.

Selected skull variables	Function number and coefficients of each discriminant function								
	1	2	3	4	5	6	7	8	9
Maximum cranial length	0.039	0.037	0.053	0.041			0.050	0.073	
Cranial base length	0.086	0.106		0.093		0.130	0.120		
Maximum frontal breadth	0.085	0.092	0.062		0.040	0.095	0.114	0.085	
Basion-Bregmatic height			0.090		0.102			0.100	
Upper facial breadth		0.074	0.087	0.026	0.038	0.094			
Bizygomatic breadth	0.092			0.117	0.115				
Bigonial breadth									0.142
Ramal height									0.103
Constant	−38.15	−35.76	−38.16	−35.00	−38.31	−34.16	−34.41	−36.86	−20.78
Wilk’s lambda value	0.469	0.477	0.481	0.498	0.500	0.488	0.492	0.502	0.644

The sectioning point is zero (i.e., discriminant scores > 0 indicate males and scores < 0 indicate females).
Stepwise analysis was performed with the parameter “$F = 2.0$ to enter, $F = 1.99$ to remove”.

Table 4
Classification accuracy of skull measurement data.

Function	Validation	Total		Male		Female	
		%	*n*	%	*n*	%	*n*
1	1	89.5	105	87.1	70	94.3	35
	2	87.6	105	87.1	70	88.6	35
	3	91.1	45	91.3	23	90.9	22
2	1	89.9	109	88.6	70	92.3	39
	2	88.1	109	88.6	70	87.2	39
	3	87.5	48	84.0	25	91.3	23
3	1	88.1	109	87.1	70	89.7	39
	2	85.3	109	85.7	70	84.6	39
	3	87.2	47	84.0	25	90.9	22
4	1	85.7	105	84.3	70	88.6	35
	2	84.8	105	82.9	70	88.6	35
	3	86.7	45	87.0	23	86.4	22
5	1	88.5	104	87.0	69	91.4	35
	2	87.5	104	87.0	69	88.6	35
	3	88.6	44	87.0	23	90.5	21
6	1	87.2	109	84.3	70	92.3	39
	2	86.2	109	84.3	70	89.7	39
	3	87.5	48	84.0	25	91.3	23
7	1	87.3	110	85.9	71	89.7	39
	2	86.4	110	84.5	71	89.7	39
	3	87.5	48	80.0	25	95.7	23
8	1	88.2	110	87.3	71	89.7	39
	2	85.5	110	85.9	71	84.6	39
	3	91.5	47	92.0	25	90.9	22
9	1	79.0	81	78.9	57	79.2	24
	2	77.8	81	78.9	57	75.0	24
	3	93.0	43	90.5	21	95.5	22

broken and so only a limited number of discriminant functions can be applied. Therefore, we eliminated measurements that included fragile landmarks such as the prosthion, endomolare, and infradentale. In addition to broken bones, we frequently see cases where only the cranium or mandible is found. In consideration of this, separate discriminant functions were established for the variables associated with these two parts of the skull.

The classification accuracy of the nine established discriminant functions was evaluated by three types of validation. The cranial functions showed high accuracy ranging from 84.8 to 91.5%. Several other reports have established discriminant functions for the skull.[5,8,28,29] The accuracy in these reports ranged from 83.07 to 89.71% for functions constructed with four or five variables,[5] from 84.1 to 83.7% with five or seven variables,[8] from 83.5 to 87.6% with three to eight variables,[28] and from 81.1 to 85.7% with three or six variables.[29] Although the variables selected in these previously established functions were not the same as those selected in this study, the classification accuracies of the functions are similar. The mandible function showed a lower accuracy (77.8% in the worst case) compared with those for the cranium. The accuracy of previously established mandible functions ranged from 83.2 to 86.5% with three to six variables,[30] ranged from 63.6 to 84.0% with two to nine variables,[31] and was 81.5% with five variables.[29] Those results suggest that more powerful functions might be established by increasing the number of variables.

The selection of candidate variables for measurements was limited in this study because the forensic archive at the National Research Institute of Police Science was the only available source of data. If we can use many samples of intact bones, more practical and powerful discriminant functions might be established in the future. Regarding the mandible, we cannot ignore Koizumi and Kouchi's[27] suggestion that errors are increased if measurement requires the "gonion" landmark. As a result, bigonial breadth and ramal height might need to be eliminated from the functions in order to improve classification accuracy.

In recent years, a number of X-ray computed tomography technologies and magnetic resonance imaging technologies have been used in skeletal morphology research.[13,14,32–36] These technologies enable us to obtain more accurate anthropological data about modern living persons. Moreover, they enable us to reevaluate or support the traditional methods and to develop new effective methods in the fields of forensic and physical anthropology (sex estimation, age estimation, and many other studies based on bone morphology).

5. Conclusion

In summary, we have established nine discriminant functions for sex estimation of modern Japanese skulls. The classification accuracy of the functions ranged from 80 to 90% for crania and just under 80% for mandibles. Although further data collection and update of the functions will be needed in the future, these functions can be used for sex estimation of Japanese people born in the 20th century (1926–1979).

Ethical approval
None declared.

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Conflict of interest
None of the authors have any conflicts of interest associated with this study.

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References

1. Krogman WM, Iscan MY. In: *The human skeleton in forensic medicine*. Springfield, Illinois: Charles C. Thomas; 1986. p. 112–51.
2. Seta S, Yoshino M. In: *Hakkotsu-Shitai no Kantei*. Tokyo: Reibunsya; 1990. p. 108–52.
3. Pons J. The sexual diagnosis of isolated bones of the skeleton. *Hum Biol* 1955;**27**(1):12–21.
4. Fisher RA. The use of multiple measurements in taxonomic problems. *Ann Eugen* 1936;**7**:179–88.
5. Hanihara K. Sexual diagnosis of Japanese skulls and scapulae by means of discriminant function. *J Anthropol Soc Nippon* 1959;**67**:191–7.
6. Tanaka T, Hanihara K, Koizumi K. Sex determination of the modern Japanese skull by means of discriminant function. *Sapporo Med J* 1979;**48**:582–93.
7. Hanihara K, Kimura K, Minamidate T. The sexing of Japanese skeleton by means of discriminant function. *Nihon Hoigaku Zasshi* 1964;**18**(2):107–14.
8. Iscan MY, Yoshino M, Kato S. Sexual dimorphism in modern Japanese crania. *Am J Hum Biol* 1995;**7**:459–64.
9. Kharosha MA, Almadani O, Ghaleb SS, Zaki MK, Fattah YA. Sexual dimorphism of the mandible in a modern Egyptian population. *J Forensic Leg Med* 2010;**17**(4):213–5.
10. Akhlaghi M, Sheikhazadi A, Naghsh A, Dorvashi G. Identification of sex in Iranian population using patella dimensions. *J Forensic Leg Med* 2010;**17**(3): 150–5.
11. Macaluso PJ. The efficacy of sternal measurements for sex estimation in South African blacks. *Forensic Sci Int* 2010;**202**(1–3):111.e1–7.
12. Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. *J Forensic Sci* 2011;**56**(2):289–96.
13. Hou WB, Cheng KL, Tian SY, Lu YQ, Han YY, Lai Y, et al. Metric method for sex determination based on the 12th thoracic vertebra in contemporary north-easterners in China. *J Forensic Leg Med* 2012;**19**(3):137–43.
14. Raghavendra Babu YP, Kanchan T, Attiku Y, Dixit PN, Kotian MS. Sex estimation from foramen magnum dimensions in an Indian population. *J Forensic Leg Med* 2012;**19**(3):162–7.

15. Snow CC, Hartman S, Giles E, Young FA. Sex and race determination of crania by calipers and computer: a test of the Giles and Elliot discriminant functions in 52 forensic science cases. *J Forensic Sci* 1979;**24**(2):448–60.
16. Robinson MS, Bidmos MA. The skull and humerus in the determination of sex: reliability of discriminant function equations. *Forensic Sci Int* 2009;**186**(1–3): 86.e1–5.
17. Yoshino M, Matsuda H, Kubota S, Imaizumi K, Miyasaka S, Seta S. Computer-assisted skull identification system using video superimposition. *Forensic Sci Int* 1997;**90**:231–44.
18. Suzuki H. *Changes in the skull features of the Japanese people from ancient to modern times, selected papers of the 5th International Congress of Anthropological and Ethnological Sciences*. Philadelphia: University of Pennsylvania Press; 1956. p. 717–724.
19. Kouchi M. Secular changes in the Japanese head form viewed from somatometric data. *Anthropol Sci* 2004;**112**:41–52.
20. Kouchi M. Brachycephalization in Japan has ceased. *Am J Phys Anthropol* 2000;**112**:339–47.
21. Ogawa Y, Miyasaka S, Imaizumi K, Yoshino M. Reevaluation of the discriminant function analysis in sex estimation from modern Japanese crania. *Jpn J Forensic Sci Technol* 2010;**15**(1):1–13.
22. Yoshino M, Miyasaka S, Sato H, Seta S. Classification system of frontal sinus patterns by radiography. Its application to identification of unknown skeletal remains. *Forensic Sci Int* 1987;**34**(4):289–99.
23. Martin R, Saller K. *Lehrbuch der Antheropologie, dritte Aufl*. Stuttgart: Gustav Fischer Verlag; 1957.
24. Sugiyama T. A note on significance level of *F* test of stepwise variable selection in two-group discriminant analysis. *Bull Fac Sci Eng* 1986;**29**:131–2.
25. *SPSS Base 16.0 for Windows User's Guide*. Chicago, IL: SPSS Inc.; 2007.
26. Sakura H, Mizoguchi Y. Measurement errors in craniometry. *J Anthropol Soc Nippon* 1983;**91**(1):69–78.
27. Koizumi K, Kouchi M. An analysis of measurement errors in mandibulometry with special reference to their influence on the results of inter-population relationship analysis. *J Anthropol Soc Nippon* 1988;**96**:339–55.
28. Giles E, Elliot O. Sex determination by discriminant function analysis of crania. *Am J Phys Anthropol* 1963;**21**:53–68.
29. Steyn M, Iscan MY. Sexual dimorphism in the crania and mandibles of South African whites. *Forensic Sci Int* 1998;**98**(1–2):9–16.
30. Giles E. Sex determination by discriminant function analysis of mandible. *Am J Phys Anthropol* 1964;**22**:129–35.
31. Franklin D, Higgins PO, Oxnard CE, Dadour I. Discriminant function sexing of the mandible of indigenous South Africans. *Forensic Sci Int* 2008;**179**(1):84.e1–5.
32. Dang-Tran KD, Dedouit F, Joffre F, Rouge D, Roussseau H, Telmon N. Thyroid cartilage ossification and multislice computed tomography examination: a useful tool for age assessment? *J Forensic Sci* 2010;**55**(3):677–83.
33. Fourie Z, Damstra J, Gerrits PO, Ren Y. Accuracy and reliability of facial soft tissue depth measurements using cone beam computer tomography. *Forensic Sci Int* 2010;**199**(1–3):9–14.
34. Eshak GA, Ahmed HM, Abdel Gawad EA. Gender determination from hand bones length and volume using multidetector computed tomography: a study in Egyptian people. *J Forensic Leg Med* 2011;**18**(6):246–52.
35. Ishii M, Yayama K, Motani H, Sakuma A, Yasjima D, Hayakawa M, et al. Application of superimposition-based personal identification using skull computed tomography images. *J Forensic Sci* 2011;**56**(4):960–6.
36. Amin MF, Hassen EI. Sex identification in Egyptian population using multi-detector computed tomography of the maxillary sinus. *J Forensic Leg Med* 2012;**19**(2):65–9.